INVESTIGATIONS ON LIGHT AND HEAT, MADE AND PUBLISHED WHOLLY OR IN PART WITH APPROPRIATION FROM THE RUMFORD FUND.

XXVI.

CONTRIBUTIONS FROM THE PHYSICAL LABORATORY OF HARVARD UNIVERSITY.

ON A NEW METHOD FOR DETERMINING THE MECHANICAL EQUIVALENT OF HEAT.

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Communicated by Professor Trowbridge, May 26, 1885.

IN 1867 Joule published the results of his experiments for determining the mechanical equivalent of heat, by means of observations on the thermal effect of an electric current. In his experiments a calorimeter was used holding over a gallon of water, the temperature of which was taken by a thermometer. The method about to be described differs from Joule's in that the temperature is measured by the change of resistance of a wire, which is heated by a current, and no water is employed. The idea of the method was suggested by Professor John Trowbridge. Accuracy is not claimed for the results which follow, as the experiments were undertaken only with the view of ascertaining the practicability of the method.

The method of conducting the experiments was as follows. A thin ribbon of steel about 45 cm. in length and 1 mm. in breadth, and weighing .23 gr., was included in one side of a Wheatstone's bridge, by which its resistance was measured. It was then thrown into another circuit, and a transient current from twelve large Bunsen cells was passed through it. The quantity of electricity transmitted was measured by a ballistic galvanometer, and the difference of potential of the ends of the steel strip was compared with the electromotive force of a Daniell's cell by means of a quadrant electrometer. The rise in temperature of the steel was found by immediately measuring its resistance again. It had been previously found, by a series of experiments made between the temperatures of 90° and 10° C., that the resistance of the steel used was represented by the equation

$$R = a\,(1 + .00503\,\theta),$$

θ being the temperature.

If then R_0 be the initiaı resistance of the strip, and R_1 the resistance after the passage of the current,

$$R_0 = a\,(1 + \beta\,\theta_0),$$
$$R_1 = a\,(1 + \beta\,\theta_1),$$

and the rise in temperature is

$$\theta_1 - \theta_0 = \frac{R_1 - R_0}{a\,\beta}$$

If w be the weight of the strip, and s its specific heat, the quantity of heat imparted to it by the current, is

$$h = w\,s\,(\theta_1 - \theta_0) = \frac{w\,s\,(R_1 - R_0)}{a\,\beta}\,. \qquad (1.)$$

But if Q is the quantity of electricity transmitted, and E the difference of potential between the ends of the strip,

$$J\,h = Q\,E,$$

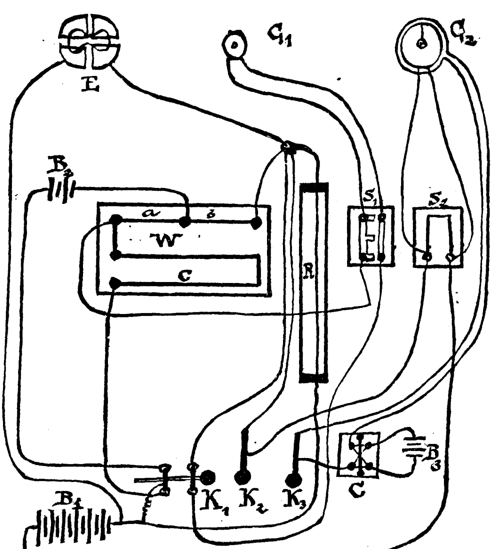
where J is the mechanical equivalent of heat. We have

$$Q = \frac{H\,T}{G\,\pi}\;2\,\sin\,\frac{a}{2}\,, \qquad (2.)$$

where a is the first swing of the needle of the ballistic galvanometer, G the galvanometer constant, T the period of a single vibration of the needle, and H the horizontal component of the earth's magnetic force. G was determined by comparison of the deflections on the scale of the ballistic galvanometer with the readings of a tangent galvanometer whose constant was calculated, included in the same circuit. In the experiments, $2\,\sin\,\frac{a}{2}$ was considered as proportional to δ, the deflection on the scale, and the value of G for $\delta = 1$ cm. was found to be 769.4. A shunt was used with the galvanometer, so that the value of Q above given is to be multiplied by $\frac{r + S}{S}$, r being the resistance of the galvanometer, and S that of the shunt.

The arrangement of the apparatus was as follows: —

R. The steel strip enclosed in a glass tube to protect it from draughts of air.
W. Wheatstone's bridge.
G_1. Thompson astatic galvanometer.
S_1. Shunt for the same.
G_2. Ballistic galvanometer.
S_2. Shunt for the same.
E. Quadrant electrometer.
B_1. Battery of twelve Bunsen cells.
B_2. Battery of two Leclanché cells.
B_3. Do. do. do.
K_1. Key for battery B_2 and galvanometer G_1.
K_2. Key for passing current from B_1 through strip.
K_3. Key in auxiliary circuit with commutator *C*, and a second coil of galvanometer G_2, for bringing the needle quickly to rest without heating strip *R*.



The two galvanometers were arranged to throw their spots of light on the same scale. The key K_1 was first depressed, *R* being then in the bridge circuit, and the spot of G_1 was brought to zero by adjusting the resistance *c*. *a* was always 1,000 ohms, and *b* one ohm. On K_1

being raised, a sufficient extra resistance was inserted in c, so that when K_2 was momentarily depressed, and K_1 was immediately afterwards again depressed, the spot G_1 did not move. The hand soon became accustomed to pressing K_2 just long enough to accomplish this result. In the experiments, c had to be increased from 1,167 ohms by the amount of 50 ohms, and the temperature of the strip accordingly rose about ten degrees. As the resistance was measured almost simultaneously with the passage of the current, the rise in temperature could be very exactly known, and the effect of radiation could be very easily determined.

Combining equations (1) and (2), we have

$$J = \frac{E\,H\,T}{G\pi}\,\delta\,\frac{(r+S)}{S}\,\frac{a\beta}{ws\,(R_1 - R_0)}\,.$$

E, as measured by the electrometer, was about one volt, $= 10^8$ C. G. S. units. H was .171; r, the resistance of the ballistic galvanometer, was 3,296 ohms; S_1, the shunt, was 1,025 ohms; T, the time of a single vibration of the needle, was 12.6 sec.; a, the resistance of the strip at 0°, was 1.072 ohms; β was .00503, the weight of the strip was .230 gr.; its specific heat, .114; the gain in resistance of the strip was .05 ohm, and δ, from twenty experiments, was 26.8 cm. G was 769.4 for $\delta = 1$.

$$J = \frac{10^8 \times .171 \times 12.6 \times 26.8 \times 4.321 \times 1.072 \times .00503}{769.4\,\pi\,.05 \times 1.025 \times .230 \times .114}$$
$$= 4.14 \times 10^7 \text{ ergs per gram-degree.}$$

In Joule's experiments, the process of heating was continued for nearly an hour, whereas here it lasts for less than a second. In the former method, it was necessary that the current should remain sensibly constant throughout the experiment, and the calorimeter was radiating heat throughout that time. In the short time required by the latter method, the radiation must be very small, and the error from the inconstancy of the current is avoided. I intend to undertake a further course of experiments in order to obtain an accurate determination, the purpose of the present paper being merely to show the method.

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